

(19) World Intellectual Property  
Organization  
International Bureau



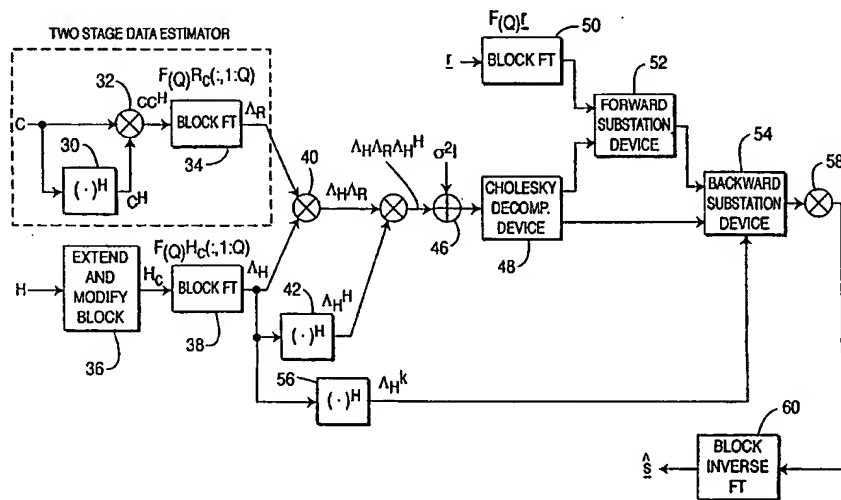
(43) International Publication Date  
29 July 2004 (29.07.2004)

PCT

(10) International Publication Number  
**WO 2004/064298 A2**

- (51) International Patent Classification<sup>7</sup>: **H04L** 236A, Holbrook, NY 11741 (US). GRIECO, Donald, M. [US/US]; 18 Shore Road, Manhasset, NY 11030 (US).
- (21) International Application Number: PCT/US2004/000463 (74) Agent: GLABICKI, Jeffrey, M.; Volpe and Koenig, P.C., United Plaza, Suite 1600, 30 South 17th Street, Philadelphia, PA 19103 (US).
- (22) International Filing Date: 8 January 2004 (08.01.2004)
- (25) Filing Language: English (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (26) Publication Language: English (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, [Continued on next page]
- (30) Priority Data: 60/439,284 10 January 2003 (10.01.2003) US
- (71) Applicant (for all designated States except US): INTER-DIGITAL TECHNOLOGY CORPORATION [US/US]; 3000 Delaware Avenue, Suite 527, Wilmington, DE 19801 (US).
- (72) Inventors; and
- (75) Inventors/Applicants (for US only): PAN, Jung-Lin [—/US]; 15 Court Street, Selden, NY 11784 (US). HUANG, Yuejin [CN/US]; 865 Broadway Avenue, Apt.

(54) Title: GENERALIZED TWO-STAGE DATA ESTIMATION



(57) Abstract: Symbols are to be recovered from signals received in a shared spectrum. Codes of the signals received in the shared spectrum are processed using a block Fourier transform (FT), producing a code block diagonal matrix. A channel response of the received signals is estimated. The channel response is extended and modified to produce a block circulant matrix and a block FT is taken, producing a channel response block diagonal matrix. The code block diagonal matrix is combined with the channel response block diagonal matrix. The received signals are sampled and processed using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm. A block inverse FT is performed on a result of the Cholesky algorithm to produce spread symbols. The spread symbols are despread to recover symbols of the received signals.



TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

**Published:**

- *without international search report and to be republished upon receipt of that report*

## GENERALIZED TWO-STAGE DATA ESTIMATION

## [0001] FIELD OF INVENTION

[0002] The present invention relates to wireless communication systems. More particularly, the present invention is directed to data estimation in such systems.

## [0003] BACKGROUND

[0004] In wireless systems, joint detection (JD) is used to mitigate inter-symbol interference (ISI) and multiple-access interference (MAI). JD is characterized by good performance but high complexity. Even using approximate Cholesky or block Fourier transforms with Cholesky decomposition algorithms, the complexity of JD is still very high. When JD is adopted in a wireless receiver, its complexity prevents the receiver from being implemented efficiently. This evidences the need for alternative algorithms that are not only simple in implementation but also good in performance.

[0005] To overcome this problem, prior art receivers based on a channel equalizer followed by a code despreaders have been developed. These types of receivers are called single user detection (SUD) receivers because, contrary to JD receivers, the detection process does not require the knowledge of channelization codes of other users. SUD tends to not exhibit the same performance as JD for most data rates of interest, even though its complexity is very low. Accordingly, there exists a need for low complexity high performance data detectors.

## [0006] SUMMARY

[0007] Symbols are to be recovered from signals received in a shared spectrum. Codes of the signals received in the shared spectrum are processed using a block Fourier transform (FT), producing a code block diagonal matrix. A channel response of the received signals is estimated. The channel response is extended and modified to produce a block circulant matrix and a block FT is taken, producing a channel response block diagonal matrix. The code block

diagonal matrix is combined with the channel response block diagonal matrix. The received signals are sampled and processed using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm. A block inverse FT is performed on a result of the Cholesky algorithm to produce spread symbols. The spread symbols are despread to recover symbols of the received signals.

[0008] BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Figure 1 is a block diagram showing a two stage data detection.

[0010] Figure 2 is a block diagram of an embodiment of two-stage data detection.

[0011] Figure 3 is a block diagram of code assignment to reduce the complexity of two-stage data detection.

[0012] Figure 4A-4D are block diagrams of utilizing look-up tables to determine  $\Lambda_R$ .

[0013] DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0014] The present invention will be described with reference to the drawing figures where like numerals represent like elements throughout.

[0015] A two stage data estimator can be used in WTRU or base station, when all of the communications to be detected by the estimator experience a similar channel response. Although the following is described in conjunction with the preferred proposed third generation partnership project (3GPP) wideband code division multiple access (W-CDMA) communication system, it is applicable to other systems.

[0016] Figure 1 is a simplified block diagram of a receiver using a two stage data estimator 55. An antenna 50 or antenna array receives radio frequency signals. The signals are sampled by a sampling device 51, typically at the chip rate or at a multiple of the chip rate, producing a received vector  $\underline{r}$ . A channel estimation device 53 using a reference signal, such as a midamble sequence or

pilot code, estimates the channel response for the received signals as a channel response matrix  $H$ . The channel estimation device 53 also estimates the noise variance,  $\sigma^2$ .

[0017] The channel equalizer 52 takes the received vector  $\underline{r}$  and equalizes it using the channel response matrix  $H$  and the noise variance  $\sigma^2$ , producing a spread symbol vector  $\underline{s}$ . Using codes  $C$  of the received signals, a despreader 54 despreads the spread symbol vector  $\underline{s}$ , producing the estimated symbols  $\underline{d}$ .

[0018] With joint detection (JD), a minimum mean square error (MMSE) formula with respect to the symbol vector  $\underline{d}$  can be expressed as:

$$\hat{\underline{d}} = (A^H R_n^{-1} A + R_d^{-1})^{-1} A^H R_n^{-1} \underline{r},$$

Equation (1)

or

$$\hat{\underline{d}} = R_d A^H (A R_d A^H + R_n)^{-1} \underline{r},$$

Equation (2)

$\hat{\underline{d}}$  is the estimate of  $\underline{d}$ ,  $\underline{r}$  is the received signal vector,  $A$  is the system matrix,  $R_n$  is the covariance matrix of noise sequence,  $R_d$  is the covariance matrix of the symbol sequence and the notation  $(\cdot)^H$  denotes the complex conjugate transform (Hermitian) operation. The dimensions and structures of the above vectors and matrices depend on specific system design. Usually, different systems have different system parameters such as frame structure, length of data field and length of delay spread.

[0019] The matrix  $A$  has the different values of dimensions for different systems and the dimensions of matrix  $A$  depend on the length of data field, number of codes, spreading factor and length of delay spread. By way of example, for the transmission of 8 codes with spreading factor 16 each, the matrix  $A$  has dimensions of 1032 by 488 for a WCDMA TDD system if burst type 1 is used and for delay spread of 57 chips long, while matrix  $A$  has dimensions of 367 by 176 for TD-SCDMA system for a delay spread of 16 chips long.

[0020] Assuming white noise and uncorrelated symbols with unity energy,  $R_n = \sigma^2 I$  and  $R_d = I$ , where  $I$  denotes the identity matrix. Substitution of these into Equations 1 and 2 results in:

$$\hat{\underline{d}} = (A^H A + \sigma^2 I)^{-1} A^H \underline{r}, \quad \text{Equation (3)}$$

or

$$\hat{\underline{d}} = A^H (A A^H + \sigma^2 I)^{-1} \underline{r}. \quad \text{Equation (4)}$$

[0021] The received signal can be viewed as a composite signal, denoted by  $\underline{s}$ , passed through a single channel. The received signal  $\underline{r}$  may be represented by  $\underline{r} = H \underline{s}$ , where  $H$  is the channel response matrix and  $\underline{s}$  is the composite spread signal.  $H$  takes the form of:

$$\underline{H} = \begin{bmatrix} h_0 & & & & & & & & & \\ & h_1 & h_0 & & & & & & & \\ & & h_1 & & & & & & & \\ & & & \ddots & & & & & & \\ & & & & \ddots & & & & & \\ h_{W-1} & & & & & \ddots & & & & \\ & h_{W-1} & & & & & \ddots & & & \\ & & & & & & & \ddots & & \\ & & & & & & & & \ddots & \\ & & & & & & & & & h_0 \\ & & & & & & & & & h_1 \\ & & & & & & & & & & \ddots \\ & & & & & & & & & & & \ddots \\ & & & & & & & & & & & & h_{W-1} \end{bmatrix}$$

Equation (5)

[0022] In Equation (5),  $W$  is the length of the channel response, and is therefore equal to the length of the delay spread. Typically  $W=57$  for W-CDMA time division duplex (TDD) burst type 1 and  $W=16$  for time division synchronous

CDMA (TD-SCDMA). The composite spread signal  $\underline{s}$  can be expressed as  $\underline{s} = C\underline{d}$ , where the symbol vector  $\underline{d}$  is:

$$\underline{d} = (d_1, d_2, \dots, d_{KN_s})^T,$$

Equation (6)

and the code matrix  $C$  is:

$$C = [C^{(1)}, C^{(2)}, \dots, C^{(K)}]$$

Equation (7)

with:

$$C^{(k)} = \begin{bmatrix} c_1^{(k)} & & & & & \\ & \ddots & & & & \\ & & c_Q^{(k)} & & & \\ & & & c_1^{(k)} & & \\ & & & & \ddots & \\ & & & & & c_Q^{(k)} \\ & & & & & & \ddots & \\ & & & & & & & c_1^{(k)} \\ & & & & & & & & \ddots \\ & & & & & & & & & c_Q^{(k)} \end{bmatrix}$$

Equation (8)

[0023]  $Q, K$  and  $N_s$  denote the spread factor (SF), the number of active codes and the number of symbols carried on each channelization code, respectively.  $c_i^{(k)}$  is the  $i^{\text{th}}$  element of the  $k^{\text{th}}$  code. The matrix  $C$  is a matrix of size  $N_s \cdot Q$  by  $N_s \cdot K$ .

[0024] Substitution of  $A = HC$  into Equation (4) results in:

$$\hat{\underline{d}} = C^H H^H (H R_c H^H + \sigma^2 I)^{-1} \underline{r}$$

Equation (9)

[0026]  $R_c = CC^H$ . If  $\hat{\underline{s}}$  denotes the estimated spread signal, Equation (9) can be expressed in two stages:

[0027] Stage 1:

$$\hat{\underline{s}} = H^H (HR_c H^H + \sigma^2 I)^{-1} \underline{r}$$

Equation (10)

[0028] Stage 2:

$$\hat{\underline{d}} = C^H \hat{\underline{s}}$$

Equation (11)

[0029] The first stage is the stage of generalized channel equalization. It estimates the spread signal  $\underline{s}$  by an equalization process per Equation 10. The second stage is the despreading stage. The symbol sequence  $\underline{d}$  is recovered by a despreading process per Equation 11.

[0030] The matrix  $R_c$  in Equation 9 is a block diagonal matrix of the form:

$$R_c = \begin{bmatrix} R_0 & & & \\ & R_0 & & \\ & & O & \\ & & & R_0 \end{bmatrix},$$

Equation (12)

[0031] The block  $R_0$  in the diagonal is a square matrix of size  $Q$ . The matrix  $R_c$  is a square matrix of size  $N_s \cdot Q$ .

[0032] Because the matrix  $R_c$  is a block circular matrix, the block Fast Fourier transform (FFT) can be used to realize the algorithm. With this approach the matrix  $R_c$  can be decomposed as:

$$R_c = F_{(Q)}^{-1} \Lambda_R F_{(Q)}$$

Equation (13)

with



$$F_{(Q)} = F_{Ns} \otimes I_Q$$

Equation (14)

[0033]  $F_{Ns}$  is the  $N_s$ -point FFT matrix,  $I_Q$  is the identity matrix of size  $Q$  and the notation  $\otimes$  is the Kronecker product. By definition, the Kronecker product  $Z$  of matrix  $X$  and  $Y$ , ( $Z = X \otimes Y$ ) is:

$$Z = \begin{bmatrix} x_{11}Y & x_{12}Y & \Lambda & x_{1N}Y \\ x_{21}Y & x_{22}Y & & x_{2N}Y \\ M & & O & \\ x_{M1}Y & x_{M2}Y & & x_{MN}Y \end{bmatrix}$$

Equation (15)

$x_{m,n}$  is the  $(m,n)^{th}$  element of matrix  $X$ . For each  $F_{(Q)}$ , a  $N_s$ -point FFT is performed  $Q$  times.

$\Lambda_R$  is a block-diagonal matrix whose diagonal blocks are:

$F_{(Q)} R_C(:, 1:Q)$ . That is,

$$diag(\Lambda_R) = F_{(Q)} R_C(:, 1:Q),$$

Equation (16)

$R_C(:, 1:Q)$  denotes the first  $Q$  columns of matrix  $R_C$ .

[0034] The block circular matrix can be decomposed into simple and efficient FFT components, making a matrix inverse more efficient and less complex. Usually, the large matrix inverse is more efficient when it is performed in the frequency domain rather than in a time domain. For this reason, it is advantage to use FFT and the use of a block circular matrix enables efficient FFT implementation. With proper partition, the matrix  $H$  can be expressed as a approximate block circular matrix of the form:

$$H = \begin{bmatrix} H_0 & & & & & \\ H_1 & H_0 & & & & \\ H_2 & H_1 & & & & \\ H_{L-1} & H_2 & & & & \\ & H_{L-1} & & & & \\ & & O & & & \\ & & & H_0 & & \\ & & & H_1 & & \\ & & & H_2 & & \\ & & & H_{L-1} & & \end{bmatrix},$$

Equation (17)

where each  $H_i$ ,  $i=0,1,\dots,L-1$  is a square matrix of size  $Q$ .  $L$  is the number of data symbols affected by the delay spread of propagation channel is expressed as:

$$L = \left\lceil \frac{Q+W-1}{Q} \right\rceil. \quad \text{Equation (18)}$$

[0035] To enable block FFT decomposition,  $H$  can be extended and modified into an exactly block circular matrix of the form:

$$H_c = \begin{bmatrix} H_0 & & & H_{L-1} & H_2 & H_1 \\ H_1 & H_0 & & & H_{L-1} & H_2 \\ H_2 & H_1 & & & & H_{L-1} \\ H_{L-1} & H_2 & & & & \\ & H_{L-1} & & & & \\ & & O & & & \\ & & & H_0 & & \\ & & & H_1 & H_0 & \\ & & & H_2 & H_1 & H_0 \\ & & & H_{L-1} & H_2 & H_1 & H_0 \end{bmatrix} \quad \text{Equation (19)}$$

[0037] The block circular matrix  $H_c$  is obtained by expanding the columns of matrix  $H$  in Equation (17) by circularly down-shifting one element block successively.

[0039] The matrix  $H_c$  can be decomposed by block FFT as:

$$H_c = F_{(Q)}^{-1} \Lambda_H F_{(Q)}$$

Equation (20)

[0040]  $\Lambda_H$  is a block-diagonal matrix whose diagonal blocks are  $F_{(Q)} H_c(:, 1:Q)$ , as  $\text{diag}(\Lambda_H) = F_{(Q)} H_c(:, 1:Q)$

Equation (21)

[0041]  $H_c(:, 1:Q)$  denotes the first Q columns of matrix  $H_c$ . From Equation (20),  $H_c^H$  can be defined as

$$H_c^H = F_{(Q)}^{-1} \Lambda_H^H F_{(Q)}$$

Equation (22)

Substituting matrix  $R_c$  and  $H_c$  into Equation 10,  $\hat{\underline{z}}$  is obtained:

$$[0042] \quad \hat{\underline{z}} = F_{(Q)}^{-1} \Lambda_H^H (\Lambda_H \Lambda_R \Lambda_H^H + \sigma^2 I)^{-1} F_{(Q)} \underline{r}$$

Equation (23)

[0043] For a zero forcing (ZF) solution, equation 19 is simplified to

$$\hat{\underline{z}} = F_{(Q)}^{-1} \Lambda_R^{-1} \Lambda_H^{-1} F_{(Q)} \underline{r}$$

Equation (24)

[0044] The matrix inverse in Equations (23) and (24) can be performed using Cholesky decomposition and forward and backward substitutions.

[0045] In a special case of K=SF, where (the number of active codes equals the spreading factor), the matrix  $R_c$  becomes a scalar-diagonal matrix with identical diagonal elements equal to SF. In this case, Equations (10) and (11) reduce to:

$$\hat{\underline{z}} = H^H (H H^H + \frac{\sigma^2}{Q} I)^{-1} \underline{r}$$

Equation (25)

and

$$\hat{\underline{d}} = \frac{1}{Q} C^H \hat{\underline{z}}$$

Equation (26)

[0046] Equation (25) can also be expressed in the form of:

$$\hat{\underline{z}} = (H^H H + \frac{\sigma^2}{Q} I)^{-1} H^H \underline{r}$$

Equation (27)

[0047] With FFT, Equations (25) and (27) can be realized by:

$$\hat{\underline{z}} = F^{-1} \Lambda_H^* (\Lambda_H \Lambda_H^* + \frac{\sigma^2}{Q} I)^{-1} F \underline{r}$$

Equation (28)

and

$$\hat{\underline{z}} = F^{-1} (\Lambda_H^* \Lambda_H + \frac{\sigma^2}{Q} I)^{-1} \Lambda_H^* F \underline{r}$$

Equation (29)

respectively.  $\Lambda_H$  is a diagonal matrix whose diagonal is  $F \cdot H(:,1)$  in which  $H(:,1)$  denotes the first column of matrix  $H$ . The notation  $(.)^*$  denotes conjugate operator.

[0048] Figure 2 is a preferred block diagram of the channel equalizer 15. A code matrix  $C$  is input into the channel equalizer 15. A Hermitian device 30 takes a complex conjugate transpose of the code matrix  $C$ ,  $C^H$ . The code matrix  $C$  and its Hermitian are multiplied by a multiplier 32, producing  $CC^H$ . A block FT performed on  $CC^H$ , producing block diagonal matrix  $\Lambda_R$ .

[0049] The channel response matrix  $H$  is extended and modified by an extend and modify device 36, producing  $H^c$ . A block FT 38 takes  $H^c$  and produces block diagonal matrix  $\Lambda_H$ . A multiplier multiplies  $\Lambda_H$  and  $\Lambda_R$  together, producing  $\Lambda_H \Lambda_R$ . A Hermitian device 42 takes the complex conjugate transpose of  $\Lambda_H$ , producing  $\Lambda_H^H$ . A multiplier 44 multiplies  $\Lambda_H^H$  to  $\Lambda_H \Lambda_R$ , producing  $\Lambda_H \Lambda_R \Lambda_H^H$  to  $\sigma^2 I$ , A, producing  $\Lambda_H \Lambda_R \Lambda_H^H + \sigma^2 I$ .

[0050] A Cholesky decomposition device 48 produces a Cholesky factor. A block FT 50 takes a block FT of the received vector  $\underline{r}$ . Using the Cholesky factor and the FT of  $\underline{r}$ , forward and backward substitution are performed by a forward substitution device 52 and backward substitution device 54.

[0051] A conjugation device 56 takes the conjugate of  $\Lambda_H$ , producing  $\Lambda_H^*$ .

The result of backward substitution is multiplied to  $\Lambda_H^*$ . A block inverse FT 60 takes a block inverse FT of the multiplied result, producing  $\hat{\underline{s}}$ .

[0052] According to another embodiment of the present invention, an approximate solution is provided in which the generalized two-stage data detection process is a block-diagonal-approximation. The block-diagonal-approximation includes off-diagonal entries as well as the diagonal entries in the approximation process.

[0053] As an example, the case of four channelization codes is considered.  $R_0$ , a combination of four channelization codes, comprises a constant block diagonal part, which does not vary with the different combinations of the codes, and an edge part which changes with the combinations. In general  $R_0$  has the structure of:

$$R_0 = \begin{bmatrix} c & c & x & x & & & & \\ c & c & x & x & & & & \\ x & x & c & c & & & & \\ x & x & c & c & & & & \\ & & & & O & & & \\ & & & & & O & & \\ & & & & & & c & c & x & x \\ & & & & & & c & c & x & x \\ & & & & & & x & x & c & c \\ & & & & & & x & x & c & c \end{bmatrix} \quad \text{Equation (30)}$$

[0054] where elements denoted as c represent constants and are always equal to the number of channelization codes, i.e.,  $c = K$ . The elements designated as x represent some variables whose values and locations vary with different combinations of channelization codes. Their locations vary following certain patterns depending on combinations of codes. As a result only a few of them are non-zero. When code power is considered and is not unity power, the element c equals the total power of transmitted codes. A good approximation of the matrix  $R_0$  is to include the constant part and ignore the variable part as:

[0056]

$$\hat{R}_0 = \begin{bmatrix} c & c & & & & & \\ c & c & & & & & \\ & & c & c & & & \\ & & c & c & & & \\ & & & & 0 & & \\ & & & & & 0 & \\ & & & & & & c & c \\ & & & & & & c & c \\ & & & & & & & c & c \\ & & & & & & & c & c \end{bmatrix}$$

Equation (31)

[0057] In this case, the approximation  $\hat{R}_0$  contains only a constant part.  $\hat{R}_0$  depends only on the number of active codes regardless of which codes are transmitted, and  $\hat{R}_c$  can be decomposed as shown in Equation (13). The block diagonal of  $\Lambda_R$  or  $F_{\omega} \hat{R}_c(:, 1:Q)$  can be pre-calculated using an FFT for different numbers of codes and stored as a look-up table. This reduces the computational complexity by not computing  $F_{\omega} R_c(:, 1:Q)$ . In the case, that code power is considered and is not unity power, the element  $c$  becomes total power of active codes, (i.e.,  $c = P_T$  in which  $P_T$  is the total power of active codes). The matrix  $\hat{R}_0$  can be expressed as

[0058]

$$\hat{R}_0 = P_{avg} \cdot \begin{bmatrix} K & K & & & & & \\ K & K & & & & & \\ & & K & K & & & \\ & & K & K & & & \\ & & & & 0 & & \\ & & & & & 0 & \\ & & & & & & K & K \\ & & & & & & K & K \\ & & & & & & & K & K \\ & & & & & & & K & K \end{bmatrix}, \quad \text{Equation (32)}$$

[0059] where  $P_{avg}$  is the average code power obtained by  $P_{avg} = \frac{P_T}{K}$ . In this case, a scaling  $P_{avg}$  should be applied in the process.

[0060] Other variants of block-diagonal approximation method can be derived by including more entries other than the constant block-diagonal part. This improves performance but entails more complexity because by including variable entries the FFT for  $F_{(Q)}R_c(:,1:Q)$  has to be now recalculated as needed if the codes change. The use of more entries enhances the exact solution as all of the off-diagonal entries are included for processing.

[0061] At a given number of channelization codes, one can derive the code sets for different combinations of channelization codes that have common constant part of the correlation matrix whose values are equal to the number of channelization codes, or the total power of channelization codes when the code does not have unity code power. To facilitate the low complexity implementation, the assignment of channelization codes or resource units can be made following the rules that a code set is randomly picked among the code sets that have common constant part and those codes in the picked code set are assigned. For example of assignment of four codes, the code sets [1,2,3,4], [5,6,7,8], [9,10,11,12], ... have the common constant part in their correlation matrix. When channel assignment of four codes is made, one of those code sets should be used for optimal computational efficiency.

[0062] Figure 3 is a flow diagram of such a channel code assignment. Codes sets having a constant part are determined, step 100. When assigning codes, the code sets having the constant part are used, step 102.

[0063] Figures 4A, 4B, 4C and 4D are illustrations of preferred circuits for reducing the complexity in calculating  $\Lambda_R$ . In Figure 4A, the number of codes processed by the two stage data detector are put in a look-up table 62 and the  $\Lambda_R$  associated with that code number is used. In Figure 4B, the number of codes processed by the two stage data detector are put in a look-up table 62 and an unscaled  $\Lambda_R$  is produced. The unscaled  $\Lambda_R$  is scaled, such as by a multiplier

66 by  $P_{avg}$ , producing  $\Lambda_R$ .

[0064] In Figure 4C, the code matrix C or code identifier is input into a look-up table 68. Using the look-up table 68, the  $\Lambda_R$  is determined. The unscaled  $\Lambda_R$  is scaled, such as by a multiplier 72 by  $P_{avg}$ , producing  $\Lambda_R$ . In Figure 4D, the code matrix C or code identifier is input into a look-up table 70, producing an unscaled  $\Lambda_R$ .

\*

\*

\*



## CLAIMS

What is claimed is:

1. A method for recovering symbols from signals received in a shared spectrum, the method comprising:

processing codes of the signals received in the shared spectrum using a block Fourier transform (FT) and producing a code block diagonal matrix;

estimating a channel response of the received signals;

extending and modifying the channel response to produce a block circulant matrix and taking a block FT and producing a channel response block diagonal matrix;

combining the code block diagonal matrix and the channel response block diagonal matrix;

sampling the received signals;

processing the received signal using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm;

performing a block inverse FT on a result of the Cholesky algorithm to produce spread symbols; and

despreading the spread symbols to recover symbols of the received signals.

2. The method of claim 1 wherein the Cholesky algorithm includes determining a Cholesky factor and performing forward and backward substitution.

3. The method of claim 1 wherein the combining the code block diagonal matrix and the channel response block diagonal matrix includes adding factor of the noise variance multiplied with an identity matrix.

4. The method of claim 1 wherein the code block diagonal matrix is produced by multiplying a code matrix with a complex conjugate transpose of the code matrix and taking a block FT of a result of the multiplying.

5. The method of claim 1 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table.

6. The method of claim 1 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

7. The method of claim 1 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table.

8. The method of claim 1 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

9. The method of claim 1 wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table.

10. The method of claim 1 wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

11. A wireless transmit/receive unit (WTRU) for use in recovering symbols from signals received in a shared spectrum, the WTRU comprising:

means for processing codes of the signals received in the shared spectrum using a block Fourier transform (FT) and producing a code block diagonal matrix;

means for estimating a channel response of the received signals;

means for extending and modifying the channel response to produce a block circulant matrix and taking a block FT and producing a channel response block diagonal matrix;

means for combining the code block diagonal matrix and the channel response block diagonal matrix;

means for sampling the received signals;

means for processing the received signal using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm;

means for performing a block inverse FT on a result of the Cholesky

algorithm to produce spread symbols; and

means for despreading the spread symbols to recover symbols of the received signals.

12. The WTRU of claim 11 wherein the Cholesky algorithm includes determining a Cholesky factor and performing forward and backward substitution.

13. The WTRU of claim 11 wherein the combining the code block diagonal matrix and the channel response block diagonal matrix includes adding factor of the noise variance multiplied with an identity matrix.

14. The WTRU of claim 11 wherein the code block diagonal matrix is produced by multiplying a code matrix with a complex conjugate transpose of the code matrix and taking a block FT of a result of the multiplying.

15. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table.

16. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

17. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table.

18. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

19. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table.

20. The WTRU of claim 11 wherein the code block diagonal matrix is produced by inputting inputting codes of the received signal into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

31. A wireless transmit/receive unit (WTRU) for use in recovering symbols from signals received in a shared spectrum, the WTRU comprising:

a block Fourier transform (FT) device for processing codes of the signals received in the shared spectrum using a block FT and producing a code block diagonal matrix;

a channel estimation device for estimating a channel response of the

received signals;

an extending and modifying block for extending and modifying the channel response to produce a block circulant matrix and taking a block FT and producing a channel response block diagonal matrix;

a circuit for combining the code block diagonal matrix and the channel response block diagonal matrix;

a sampling device for sampling the received signals;

a Cholesky decomposition device and forward and backward substitution devices for processing the received signal using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm;

an inverse block FT device for performing a block inverse FT on an output of the backward substitution device to produce spread symbols; and

a despreader for despreading the spread symbols to recover symbols of the received signals.

32. The WTRU of claim 31 wherein the circuit for combining comprises a two multipliers.

33. The WTRU of claim 31 wherein the circuit for combining includes adding factor of the noise variance multiplied with an identity matrix.

34. The WTRU of claim 31 further comprising a Hermitian device and a

multiplier for multiplying a code matrix with a complex conjugate transpose of the code matrix.

35. The WTRU of claim 31 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table.

36. The WTRU of claim 31 comprising a look-up table and a multiplier wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

37. The WTRU of claim 31 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table.

38. The WTRU of claim 31 comprising a look-up table and a multiplier wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

39. The WTRU of claim 31 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table.

40. The WTRU of claim 31 comprising a look-up table and a multiplier wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

51. A base station for use in recovering symbols from signals received in a shared spectrum, the base station comprising:

means for processing codes of the signals received in the shared spectrum using a block Fourier transform (FT) and producing a code block diagonal matrix;

means for estimating a channel response of the received signals;

means for extending and modifying the channel response to produce a block circulant matrix and taking a block FT and producing a channel response block diagonal matrix;

means for combining the code block diagonal matrix and the channel response block diagonal matrix;

means for sampling the received signals;

means for processing the received signal using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm;

means for performing a block inverse FT on a result of the Cholesky algorithm to produce spread symbols; and

means for despreading the spread symbols to recover symbols of the received signals.



52. The base station of claim 51 wherein the Cholesky algorithm includes determining a Cholesky factor and performing forward and backward substitution.

53. The base station of claim 51 wherein the combining the code block diagonal matrix and the channel response block diagonal matrix includes adding factor of the noise variance multiplied with an identity matrix.

54. The base station of claim 51 wherein the code block diagonal matrix is produced by multiplying a code matrix with a complex conjugate transpose of the code matrix and taking a block FT of a result of the multiplying.

55. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table.

56. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

57. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table.

58. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

59. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table.

60. The base station of claim 51 wherein the code block diagonal matrix is produced by inputting inputting codes of the received signal into a look-up table and scaling a resulting diagonal block matrix from the look-up table by an average power level.

61. A base station for use in recovering symbols from signals received in a shared spectrum, the base station comprising:

a block Fourier transform (FT) device for processing codes of the signals received in the shared spectrum using a block FT and producing a code block diagonal matrix;

a channel estimation device for estimating a channel response of the received signals;

an extending and modifying block for extending and modifying the channel response to produce a block circulant matrix and taking a block FT and producing

a channel response block diagonal matrix;

a circuit for combining the code block diagonal matrix and the channel response block diagonal matrix;

a sampling device for sampling the received signals;

a Cholesky decomposition device and forward and backward substitution devices for processing the received signal using the combined code block diagonal matrix and the channel response block diagonal matrix with a Cholesky algorithm;

an inverse block FT device for performing a block inverse FT on an output of the backward substitution device to produce spread symbols; and

a despreader for despread the spread symbols to recover symbols of the received signals.

62. The base station of claim 61 wherein the circuit for combining comprises a two multipliers.

63. The base station of claim 61 wherein the circuit for combining includes adding factor of the noise variance multiplied with an identity matrix.

64. The base station of claim 61 further comprising a Hermitian device and a multiplier for multiplying a code matrix with a complex conjugate transpose of the code matrix.

65. The base station of claim 61 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table.

66. The base station of claim 61 comprising a look-up table and a multiplier wherein the code block diagonal matrix is produced by inputting a number of codes of interest into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

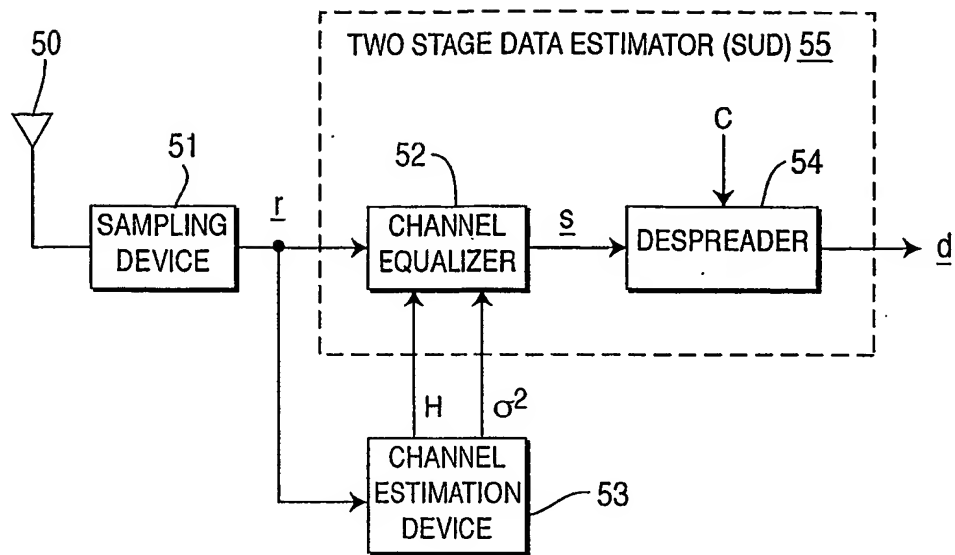
67. The base station of claim 61 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table.

68. The base station of claim 61 comprising a look-up table and a multiplier wherein the code block diagonal matrix is produced by inputting code identifiers of the received signals into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

69. The base station of claim 61 further comprising a look-up table wherein the code block diagonal matrix is produced by inputting codes of the received signal into a look-up table.

70. The base station of claim 61 comprising a look-up table and a

multiplier wherein the code block diagonal matrix is produced by inputting inputting codes of the received signal into a look-up table and multiplying a resulting diagonal block matrix from the look-up table by an average power level.

**FIG. 1**

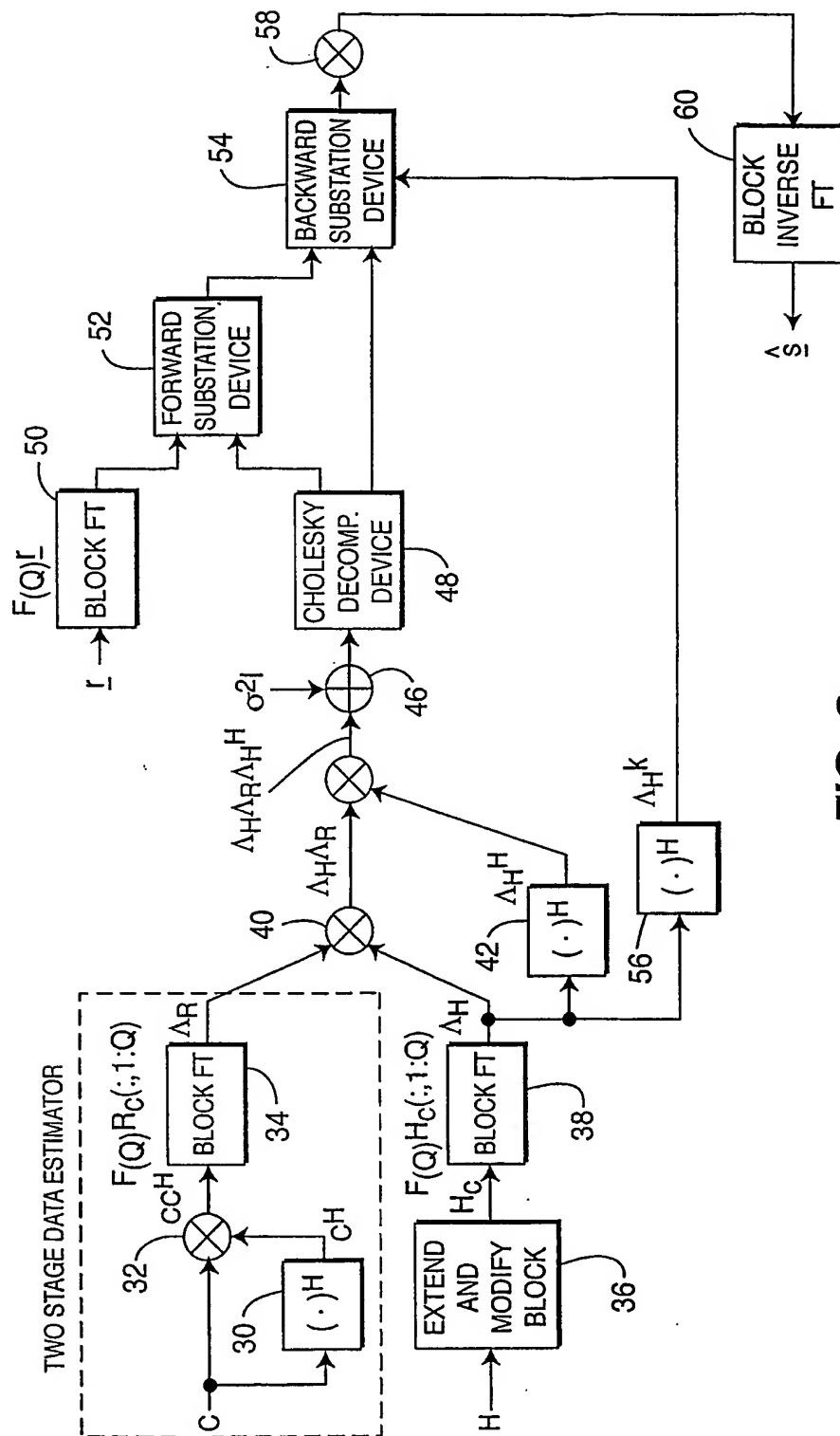
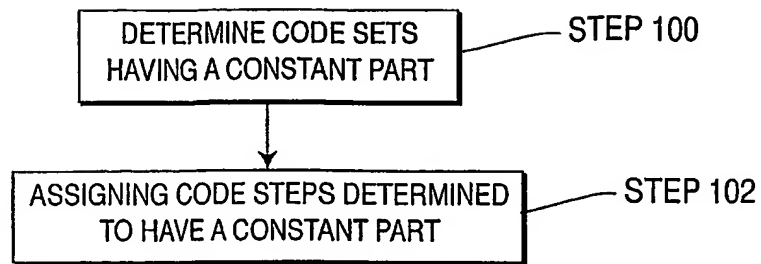
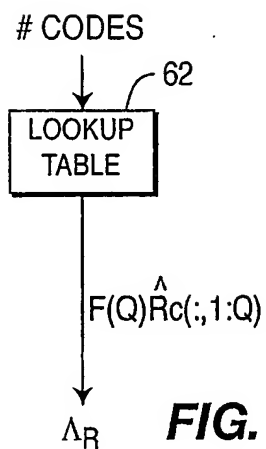
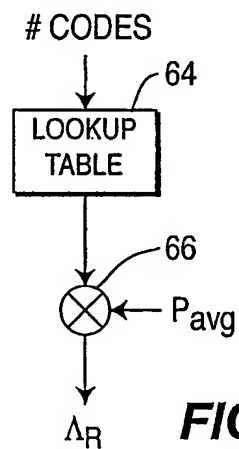
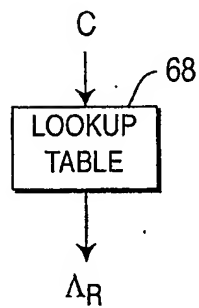
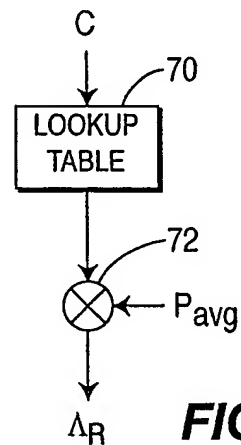


FIG. 2

**FIG. 3****FIG. 4A****FIG. 4B****FIG. 4C****FIG. 4D**



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**